# Developing Zones of Homogeneous Response for the Spokane Valley-Rathdrum Prairie Aquifer Model

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## Background

The goal of the proposed spreadsheet is to allow lay users to identify a location, magnitude, and timing for aquifer withdrawal or recharge (a stress or stresses) and determine the resulting location, magnitude, and timing of impacts on surface water bodies interconnected with the Spokane Valley-Rathdrum Prairie (SVRP) aquifer. The spreadsheet is to be based on the SVRP aquifer model which represents our best understanding of surface and ground water interactions in the basin.

The spreadsheet will provide a more aggregated look at the surface and ground water interactions in the SVRP aquifer model. The more aggregated look is needed because a) presentation of results on a cell-by-cell basis provided a misleading representation of the resolution of our knowledge and b) spatial aggregation decreases complexity creating a more user-friendly tool. Aggregation occurs by the development of zones within the aquifer and reaches associated with surface water systems. Aquifer zones are being developed in which it is assumed that the interactions with surface water bodies are the same for a stress anywhere within a given zone, and can be represented by an average response for that area. This requires that aquifer zones be developed which have minimal differences in their response to different river/lake reaches at all times. The reaches have been previously determined as follows:

1) Spokane River above Spokane Gage
2) Spokane River between Avista Dam and Deep Creek
3) Spokane River below Deep Creek and the Little Spokane River
4) Lake Coeur d'Alene
5) Lake Pend Oreille
6) Little Spokane River above Painted Rocks Gage

The surface and ground water interactions forming the basis of the spreadsheet tool were developed from a double-precision version of the SVRP MODFLOW model consisting of 120 monthly timesteps (10 years) followed by a steady state condition. The simulation represented average hydrologic conditions for the October 1995 through September 2005 period.

Using results from model runs for stresses at each cell in layer 1, a statistical software package, SYSTAT, was used to perform a cluster analysis on the cells within the model to group similar effects into

zones in the SVRP model. Several scenarios were tried during the cluster analysis prior to choosing the current assemblage of zones; however, the best result in grouping similar effects together was mainly based on (1) the time it took for the effects to reach half (50%) of their maximum response under transient conditions, and (2) the responses to all six reaches. The example in Figure 1 below further explains this response time of the cells:

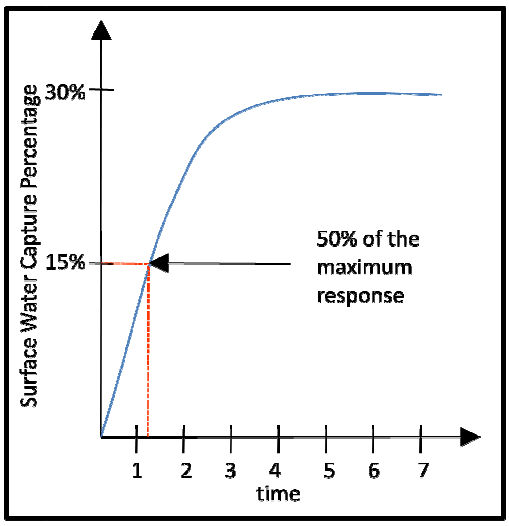


**Figure 1.** Graph of surface water capture over time.

The red dotted line in Figure 1 shows that it took about 1.25 years for the effects in the particular cell of the SVRP model to reach 50% of the maximum response during transient conditions.

How the Zones were Developed

Several scenarios were attempted in the cluster analysis to define zones within the SVRP until an acceptable assemblage was found. The final map includes 36 zones. Clusters, also referred to as bands of uniform characteristic, were developed to minimize the variation of the "time-to-50%" response considering all of the six reaches. In order to estimate these bands, three major analyses were performed. The first analysis performed included all model cells and was based on the "time-to-50%" response to all six reaches. The result is shown in Figure 2. In the Chilco Channel and northwest of Lake Pend Oreille, cluster analysis produced a large number of zones and zones of smaller spatial extent, than can be reasonably supported by the level of detail available in a regional aquifer model. The distribution of zones across the remaining areas of the SVRP appears to be as expected based on assumptions of homogeneity.

The second analysis completed included all models cells with the steady state response to all six reaches. Figure 3 shows the second analysis. This analysis shows a good distribution of zones across most of the SVRP based on assumed homogeneity; however, Figure 3 shows there are more zones detailed in the Little Spokane River Arm than can be supported by a regional model.

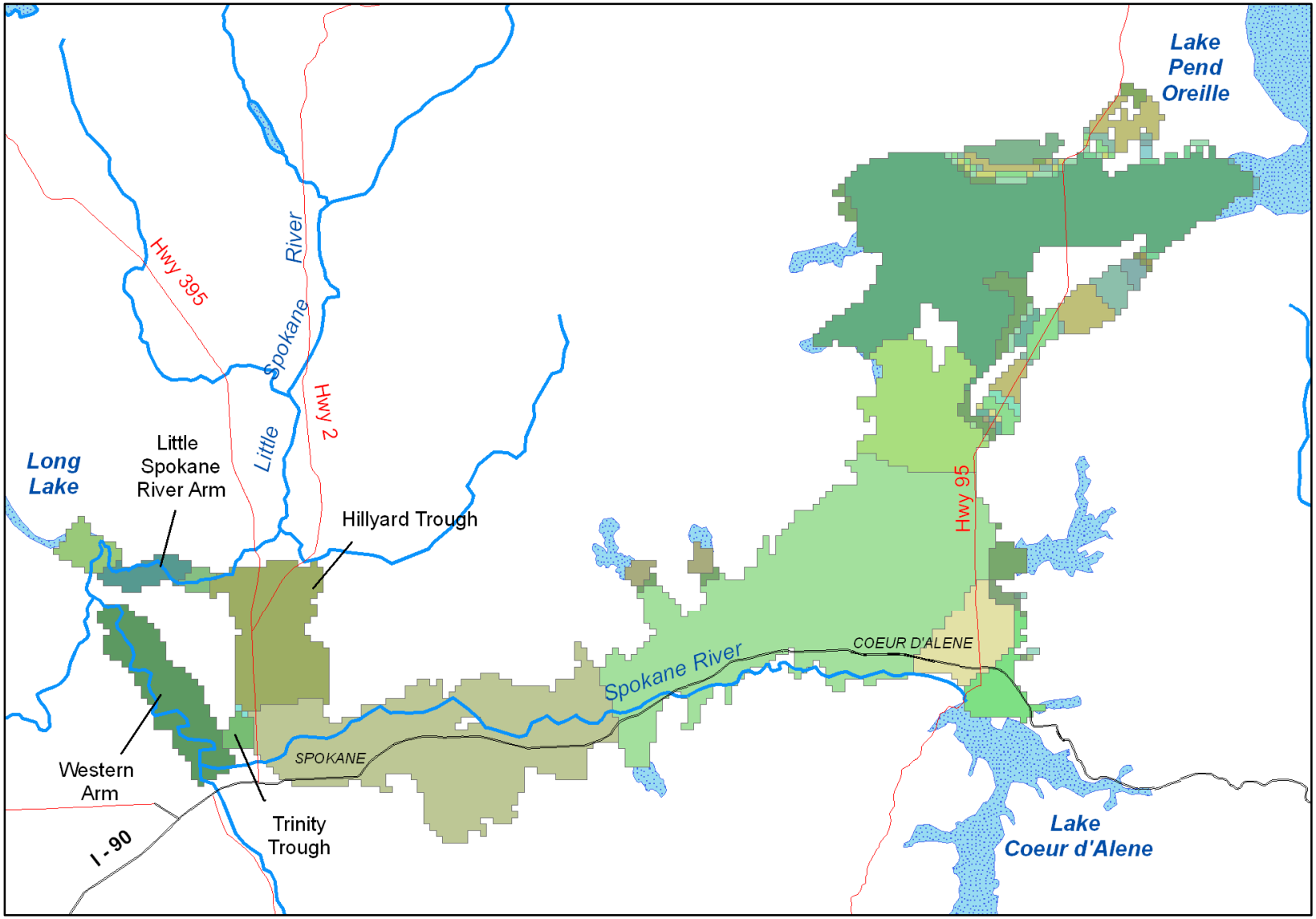


**Figure 2.** Cluster analysis based on time-to-50% response time to all six reaches with no cells excluded from the analysis.

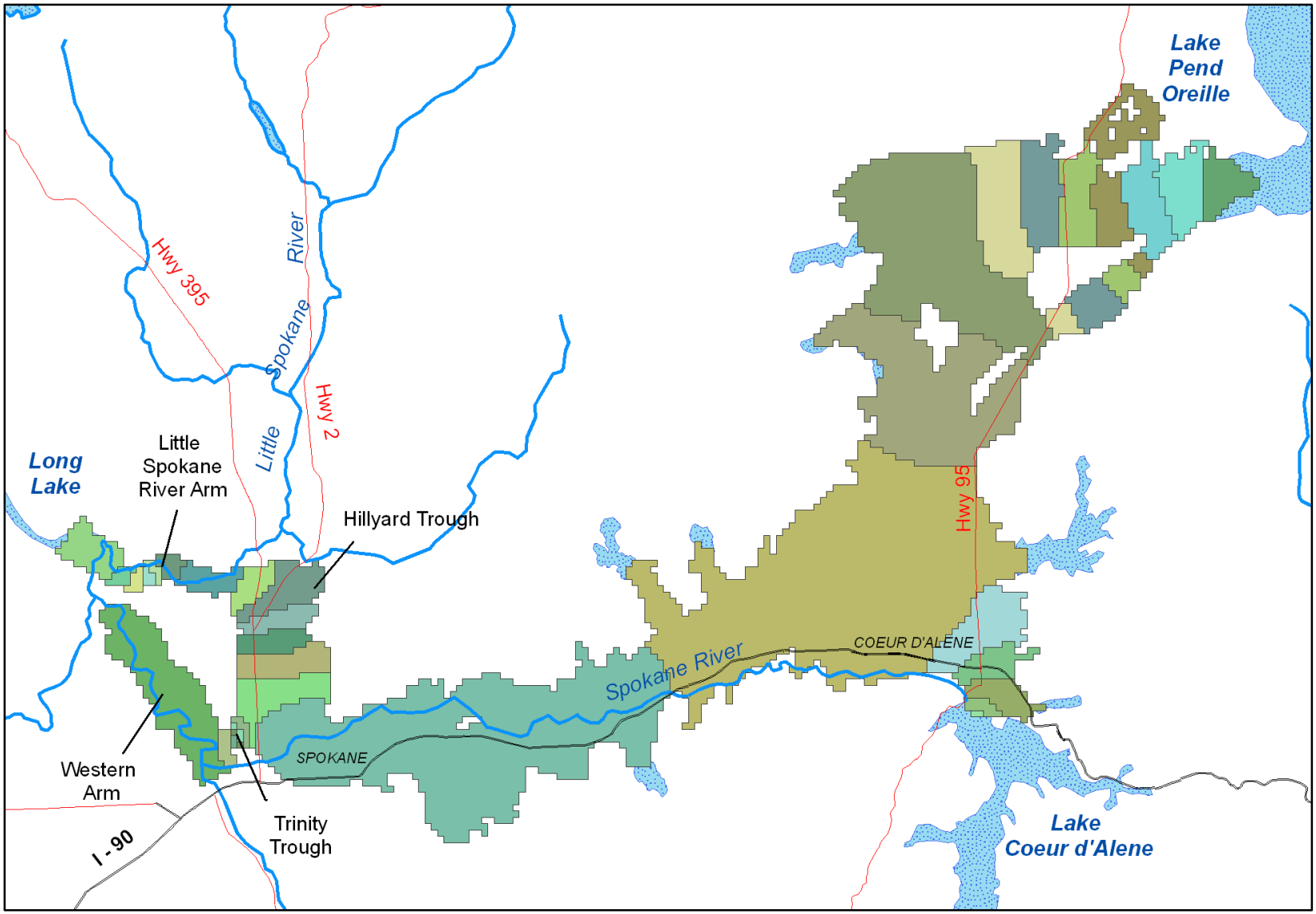


**Figure 3.** Cluster analysis based on steady-state-capture percentage to all six reaches with no cells excluded from the analysis.

The distribution of zones shown in Figures 2 and 3 do not appropriately represent bands of uniform characteristic in the SVRP; therefore, a third cluster analysis was performed. This cluster analysis was based on time-to-50%. Based on previous analyses, several cells were excluded since these areas consistently had a high degree of variability in each cluster analysis. These areas tended to consist of many small zones, which lead to neglecting the remainder of the aquifer (this neglect was caused by operation of the cluster analysis software, SYSTAT). Figure 4 shows the distribution of cells in the SVRP. All of the zones in Figure 4 with a color (non-white) were used in the cluster analysis. These colors represent bands of uniform characteristics. The white cells were excluded from the analysis. Therefore, for the construction of the final zone map, cluster analysis was repeated by omitting these white-colored regions. When zones consisted of 10 zones or less, these cells were added to a nearby zone. This was done to simplify the tool and to avoid impression of a more detailed spatial understanding than is possible with a regional aquifer model. For instance, near the northwestern end of Lake Coeur d'Alene there is a group of 2 green cells. These cells were added to the red zone above it. Similar instances are found in the northeastern end of the model near Lake Pend Oreille.

In the areas shown in white in Figure 4, zones were manually created because the small zones produced by cluster analysis implied more knowledge of detail than exists in a regional model. In three locations, the manually-created zones included all the cells in a particular geographic area: Chilco Channel, North of Athol, and Trinity Trough (zones Y, AB, and N, respectively). In the fourth area, the Little Spokane River Arm, three zones were manually created based on the results of both the time-to-50% and steady-state-capture analyses. These are zones A, B, and C.

Figure 5 shows the final distribution of zones outlined in yellow. There are a total of 36 zones labeled west to east in order alphabetically from A through AJ. Note that although there may appear to be more than 36 zones, some zones consist of two non-contiguous areas, but still share the same characteristics (examples zone R and zone AB). Zones that have high variability of response time or capture are A, B, C, D, N, Y, and AB. Four zones (A, B, C, and D) exist in the Little Spokane River Arm. Trinity trough is shown as zone M. The Chilco Chanel is represented as zone Y. Above the Northern Rathdrum Prairie (NE area of the SVRP) is represented as zone AB.

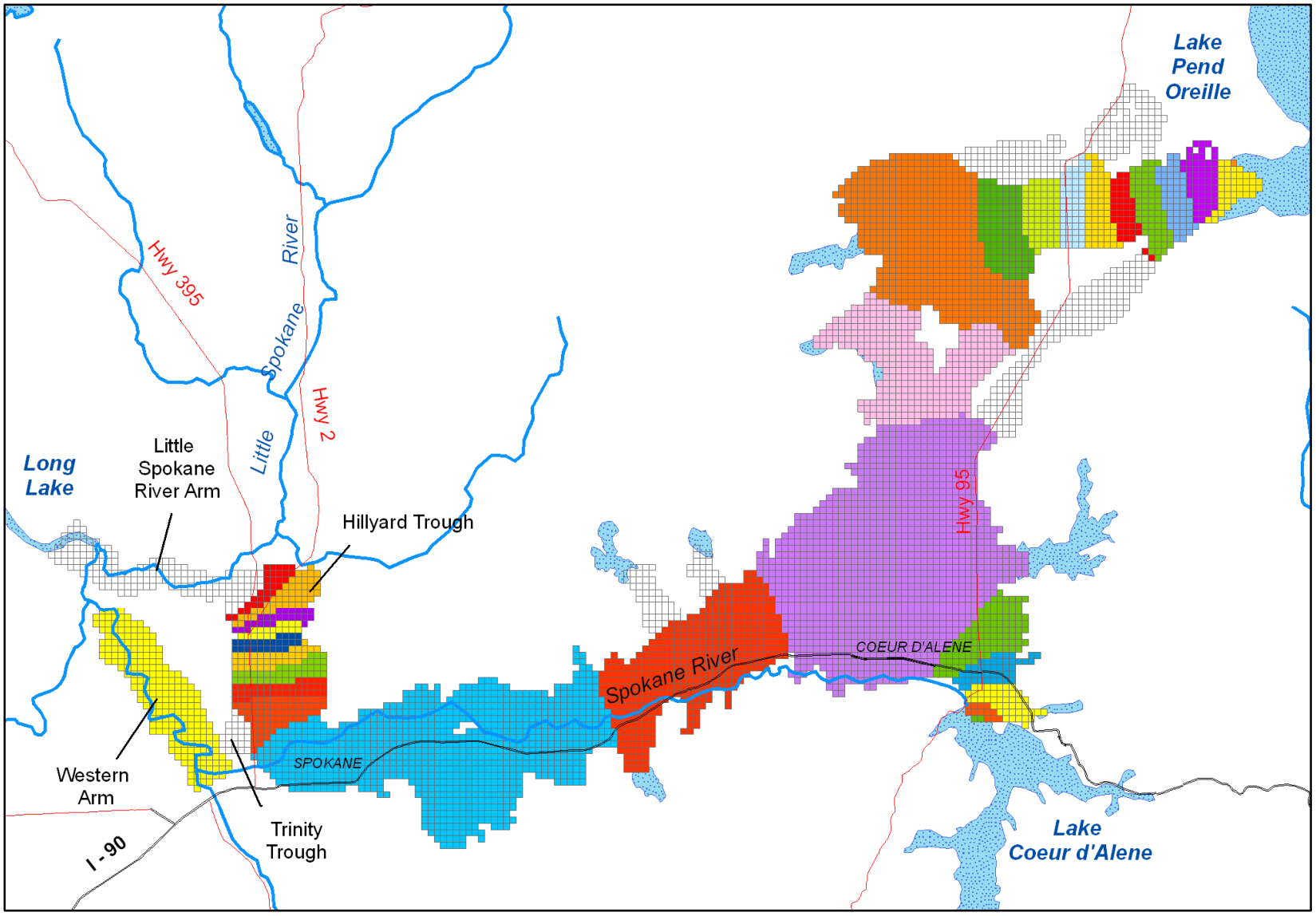


**Figure 4.** Zones created in ArcMap after cluster analysis using time-to-50% response and response to all six reaches prior to any hand manipulation. The white areas were not included in the analysis.

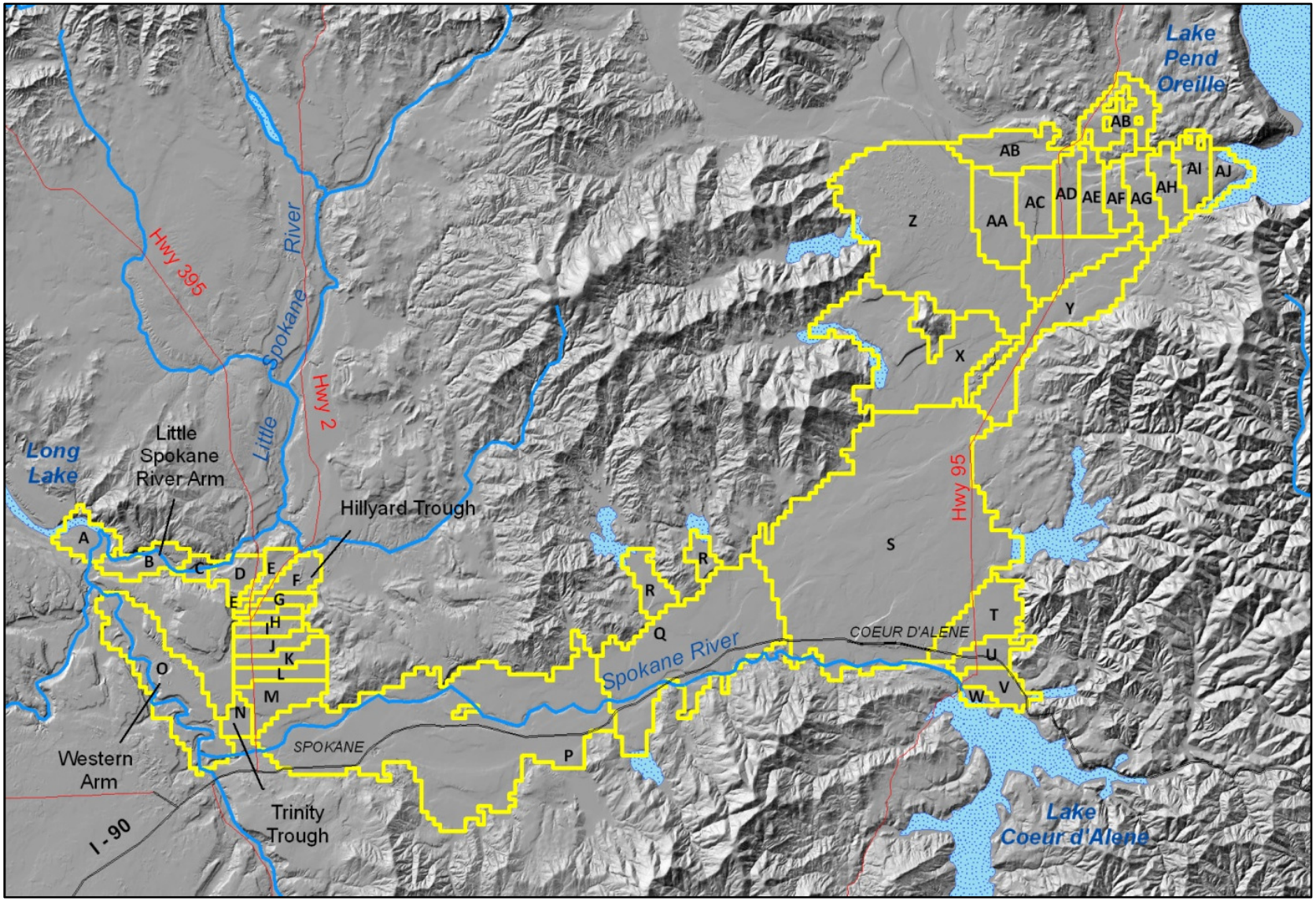


**Figure 5.** Final distribution of zones in the SVRP based on the zones in Figure 4 after hand manipulation and Figure 2 zones composing the Little Spokane River arm.

Use of the Zones

After modifying the zones through cluster analysis, further analysis was done to rank the zones based on the degree of variation of responses within the zone. The degree of variation was based on responses to transient conditions (time-to-50% response) and steady state conditions. To assess the degree of variation, maps were made of the time-to-50% variation and steady-state-capture variation for each of the six reaches. Each zone was visually assessed and resulted in twelve separate maps. Figure 6 will further explain this concept showing a portion of one of these maps, a map of the western half of the SVRP aquifer showing response to reach one after the time it takes to reach 50% of the maximum response. The zones outlined in yellow are the same zones as the zones in Figure 5. Notice that several of the zones have very uniform time-to-50% response (contain only one map color) while others span two time-to-50% categories (contain two map colors).

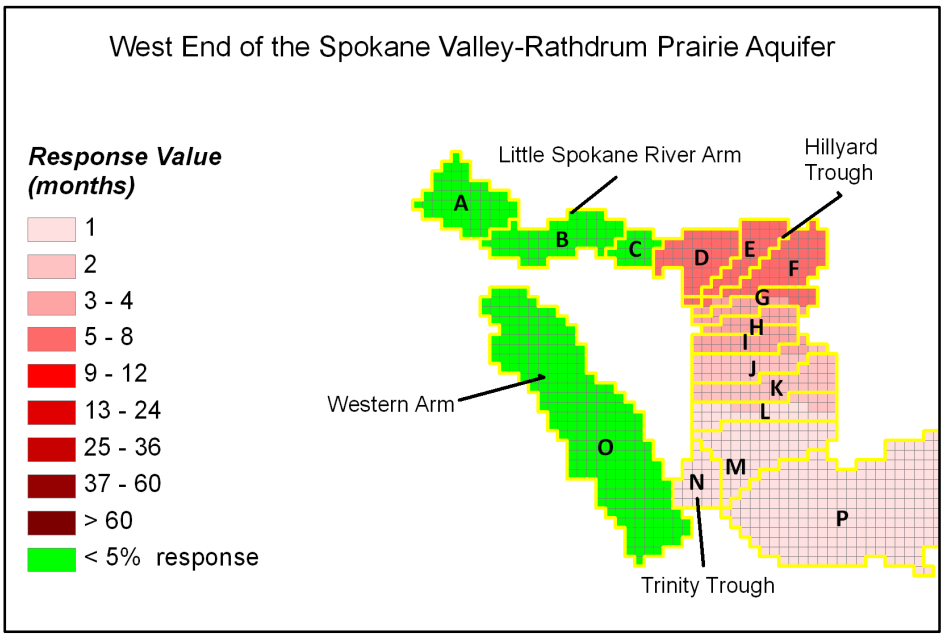


**Figure 6.** Zones in the western half of the SVRP aquifer showing the response to reach 1 for time-to-50% of maximum capture.

After visually assessing all 36 zones in all 12 maps produced, the results were compiled for all six reaches based on time-to-50% and steady-state-capture fraction. The compilation included counting the numbering of colors in each zone to estimate the uniformity based on time-to-50% response and steady state response to each of the 6 reaches. For example, if zone D in Figure 6 above consisted of one color for response to all six reaches based on steady-state and transient conditions, a number of 12 would be assigned to this zone and it would be considered uniform. Table 1 shows the number of bands (colors) per zone for both conditions (transient and steady state). The number of bands for the two groups of responses (time-to-50% and steady-state-capture percentage) were added together and the total is found in the "Sum" column. A score of "12" in the "Sum" column would be a perfect score (see Zone O). Figure 7 is a visual representation of the "Sum" column in Table 1, showing he number of colors in each zone for all 12 maps.

**Table 1.** Total number of bands per zone.

| Zone | Time-to-50% Response | Steady-State-Capture % | Sum | Map Legend Value (Figure 7) |
|---|---|---|---|---|
| A | 7 | 8 | 15 | 14-15 |
| B | 10 | 24 | 34 | 34-35 |
| C | 7 | 6 | 13 | 12-13 |
| D | 8 | 10 | 18 | 18-19 |
| E | 7 | 8 | 15 | 14-15 |
| F | 8 | 6 | 14 | 14-15 |
| G | 8 | 7 | 15 | 14-15 |
| H | 6 | 8 | 14 | 14-15 |
| I | 6 | 8 | 14 | 14-15 |
| J | 7 | 8 | 15 | 14-15 |
| K | 6 | 8 | 14 | 14-15 |
| L | 7 | 7 | 14 | 14-15 |
| M | 7 | 7 | 14 | 14-15 |
| N | 7 | 21 | 28 | 28-29 |
| O | 6 | 6 | 12 | 12-13 |
| P | 8 | 6 | 14 | 14-15 |
| Q | 7 | 8 | 15 | 14-15 |
| R | 9 | 7 | 16 | 16-17 |
| S | 11 | 7 | 18 | 18-19 |
| T | 12 | 7 | 19 | 18-19 |
| U | 11 | 8 | 19 | 18-19 |
| V | 7 | 9 | 16 | 16-17 |
| W | 7 | 8 | 15 | 14-15 |
| X | 9 | 8 | 17 | 16-17 |
| Y | 14 | 17 | 31 | 30-31 |
| Z | 10 | 8 | 18 | 18-19 |
| AA | 9 | 7 | 16 | 16-17 |
| AB | 11 | 14 | 25 | 24-25 |
| AC | 8 | 8 | 16 | 16-17 |
| AD | 9 | 8 | 17 | 16-17 |
| AE | 10 | 8 | 18 | 18-19 |
| AF | 7 | 6 | 13 | 12-13 |
| AG | 10 | 8 | 18 | 18-19 |
| AH | 10 | 6 | 16 | 16-17 |
| AI | 11 | 8 | 19 | 18-19 |
| AJ | 8 | 6 | 14 | 14-15 |

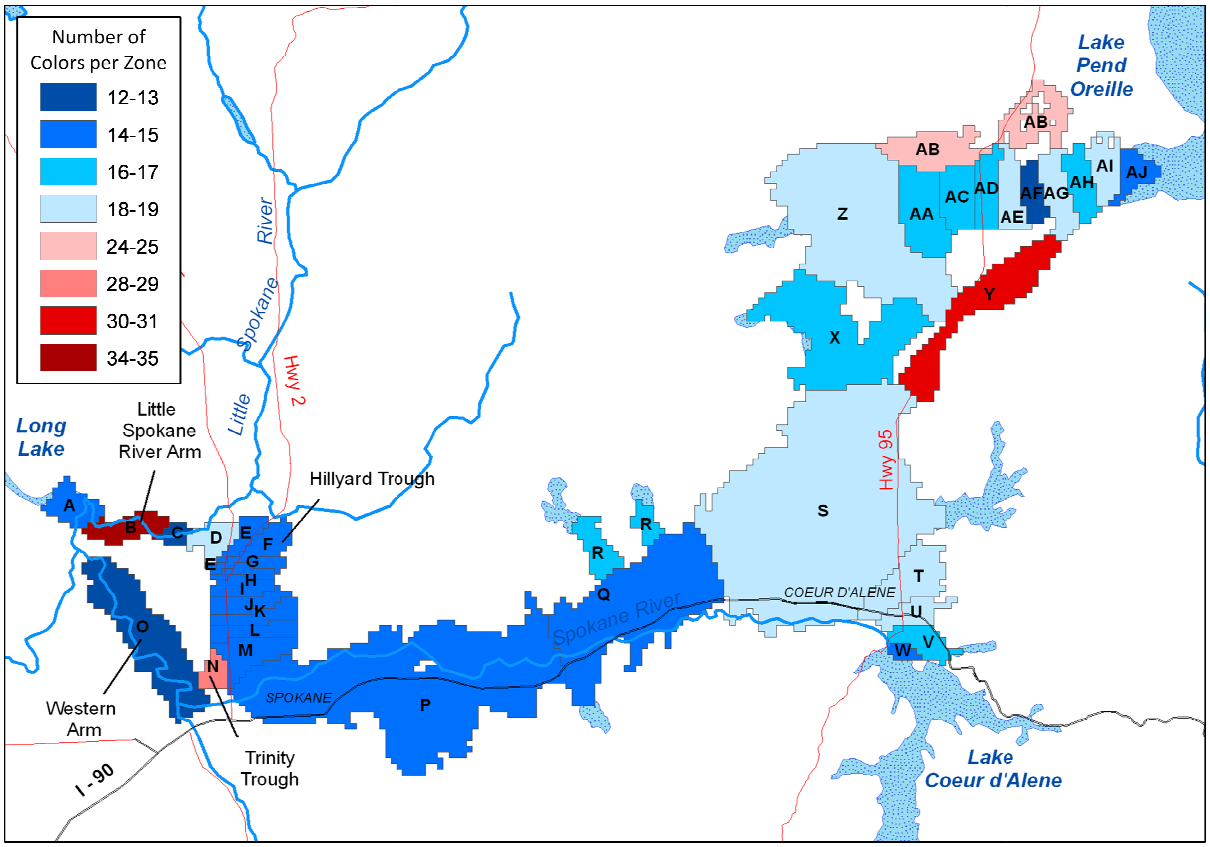


**Figure 7.** Number of colors per zone in the SVRP.

A frequency analysis was performed to visualize the degree of variability within various zones. The X-axis in Figure 8 represents the bins that were based on the "Sum" column in Table 1 (for instance, bin "18-19" contains eight zones whose score was 18 or 19). The Y-axis represents the number of zones that lie within each bin. A large majority of the zones fall within the bins between 12 and 19 while the remaining zones lie above 24. There appears to be three distinct groups as shown by the green, yellow, and red boxes. Using these groups, the zones in the map of the SVRP shown in Figure 9 were classified as to how they should be used. The tool may be used in the green zones without concern for variability in response time or capture fraction (note that non-linearity may be a concern in some areas; see [Gary's future linearity report]). The tool should be used with caution in the yellow zone since there is more variation in response of the cells within the zone. The tool is not recommended for use in the red zones since there is such a wide array of response time and/or capture fraction within each zone.

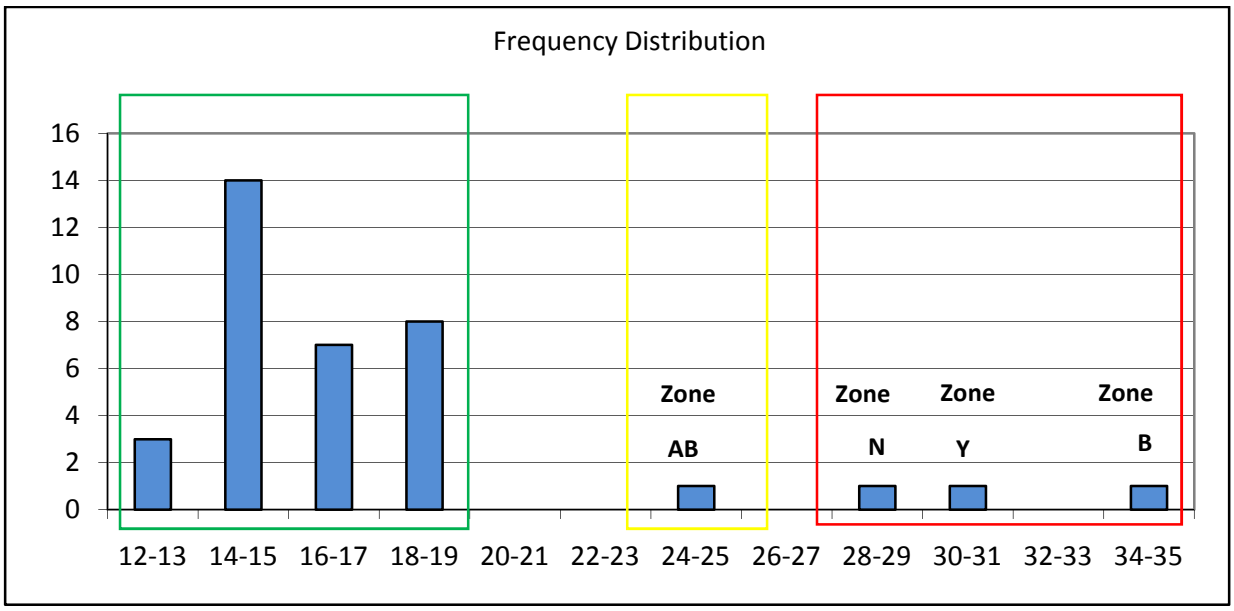


**Figure 8.** Frequency analysis showing the number of zones within each bin (a bin is "12-13" or "18-19"). Note that some bins only have one zone (Bins 24-25, 28-29, 30-31, and 34-35).

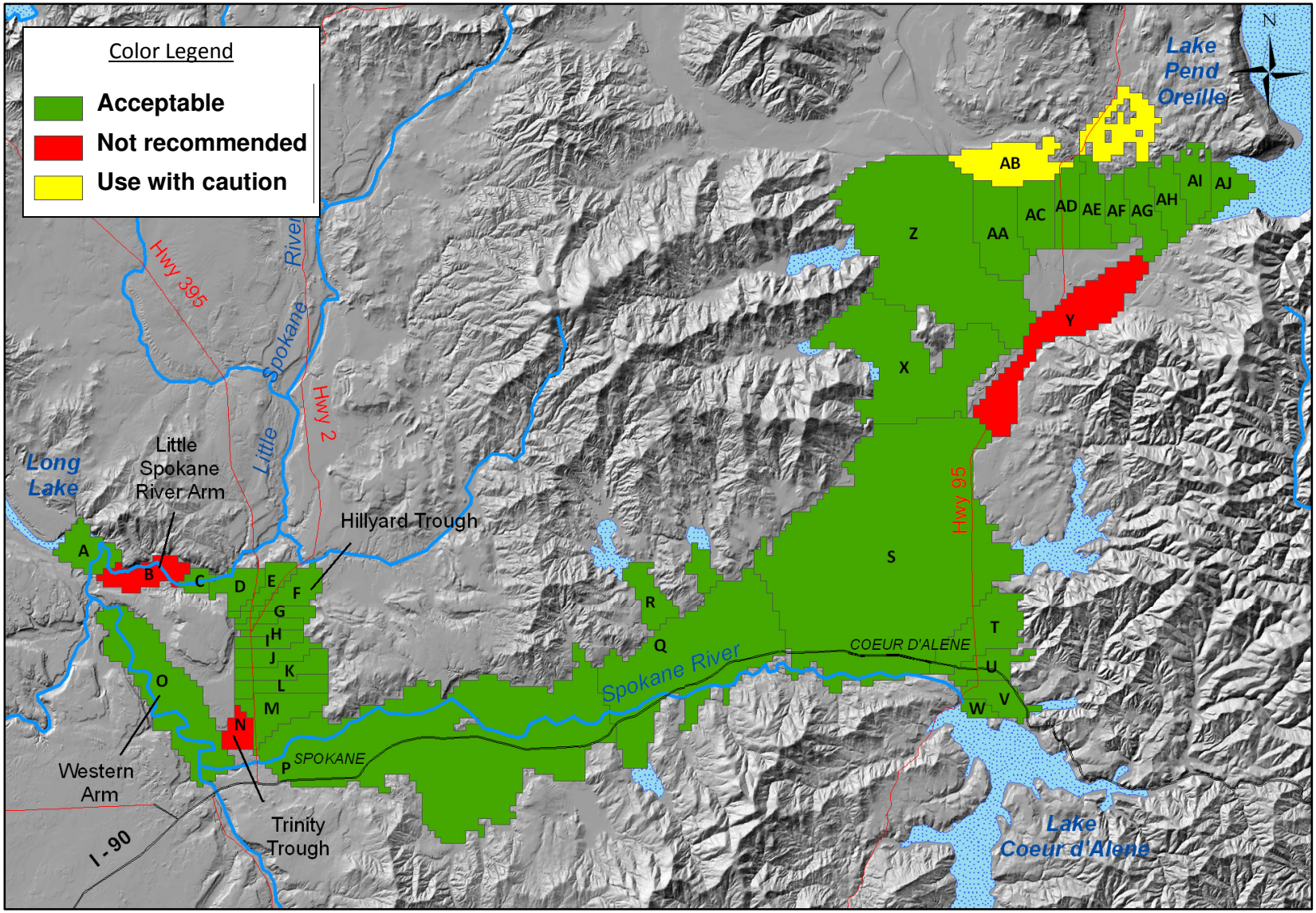


**Figure 9.** Recommendations for use of the zones in the SVRP.